International Journal Metallurgical & Materials Science and Engineering (IJMMSE)
ISSN(P): 2278-2516; ISSN(E): 2278-2524
Vol. 4, Issue 1, Feb 2014, 15-24
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ADVANCES IN ABRASIVE FLOW MACHINING: AN OVERVIEW

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ABSTRACT

Abrasive Flow Machining (AFM) means removal of material from a work piece by means of abrasive particles in a fluid-like stste.AFM started in 1960s as a method to deburr, polish and radius difficult to reach surfaces like intricate geometries and edges. Depending upon the nature of movement of the abrasive media AFM can be classified as one way AFM, two way AFM and orbital AFM. The major performance parameters in AFM are extrusion pressure, abrasive concentration, abrasive size, number of cycles and hardness of the work piece. Most of the studies in this field are carried out to asses the material removal rate (MRR)surface finish obtained with the process variables.AFM is capable of producing surface finish (R_a) of the order 0.05µm,deburr holes as small as 0.2 mmand radius edges from 0.025 mm to 1.5mm.The process capability of AFM can be increased by rotating the viscoelastc media along with the reciprocating movement of the media,which is named as centrifugal force assisted abrasive flow machining (CFAAFM).Another way of improving the MRR and Ra values is applying magnetic field across the work piece and viscoelastic media and it is known as Magneto rheologicalabrasive flow finishing (MRAFF).

KEYWORDS: Abrasive Flow Machining, Material Removal, Surface Finish, Magnetic Field Assisted Abrasive Flow Machining, Centrifugal Force Assisted Abrasive Flow Machining, Magneto Rheological Abrasive Flow Finishing

INTRODUCTION

Abrasive processes are capable of giving surface roughness in order of micron to angstrom level, depending upon the size of the abrasives and other process parameters. The main expectations from these processes are improvement of surface finishing, surface integrity and reduce or eliminate surface defects generated due to the previous process. The bonded abrasives and loose abrasives process are not effective for complex internal/external geometries. This situation motivated the researchers to think of the third class of abrasive process. In this group one of the process is viscoelastic flow machining which is popularly known as Abrasive Flow Machining (AFM).The cutting tool of this process has a distinguished viscoelastic feature which makes AFM more suitable for complex/external geometries to meet the above expectation.

The AFM system comprises mainly three elements

Machine: AFM machines are available in various size and configuration depending upon the required capacity and work piece configuration. It consists of frame structure, hydraulic cylinders, media cylinders, hydraulic power pack and control system. Pressure up to 220 bar can be generated (figure 1). The volume of flow depends upon the displacement of each media cylinder stroke and total number of cycles used to complete the job. The control and monitoring systems are also added to make the process more efficient and reliable.

Tooling: The function of tooling unit is to locate and hold the work piece in position and direct the flow media. The tooling is designed in such a way that it should restrict the flow at the domain where the material removal is required. The complexity of tooling depends on the complexity of work piece to be machined.

Media: It is a mixture of polymer and abrasives. Most frequently used polymer for this purpose is polyborosilocxane and many other grades of polymers are also used depending on the configuration of the work piece. Generally used abrasives are alumina and silicon carbide. The functions of polymer in media are to act as binder and to transmit the extrusion force, whereas the function of abrasives is to abrade the material when media is passing through a restricted area. The rheological properties govern the performance of the media. Higher viscosity is suitable for largepassage and lower viscosity is suitable for radiusing and smaller passage. The life of media is depends on many factors like initial surface roughness, nature of abrasives and ratio of mixtures.

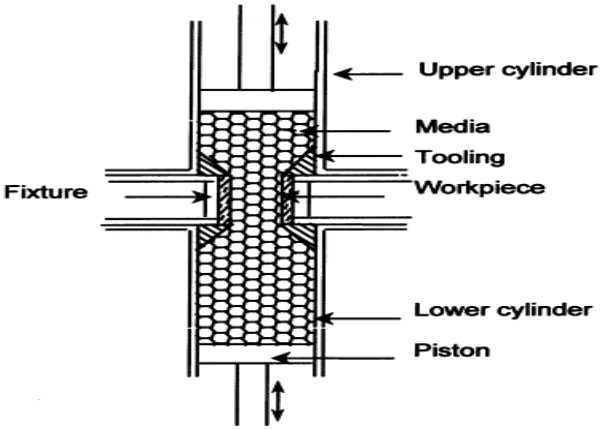


Figure 1

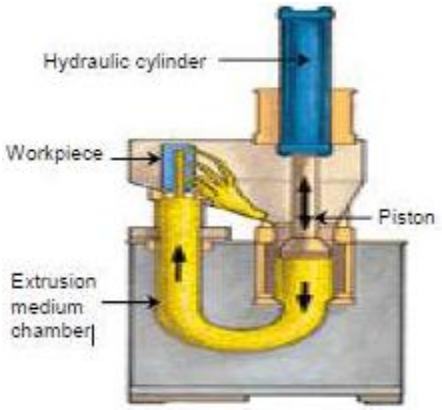


Figure 2

In this process layer thickness of the material removed is the order of 1 to 10µm.In AFM, deburring, radiusing and polishing can be performed simultaneously in various areas including normally inaccessible areas. It can process dozens of holes or multiple passage parts simultaneously with uniform results. Air cooling holes in a turbine disk and hundreds of holes in a combustion liner can be deburred and radiused in a single operation. Advanced AFM processes like CFAAFM and MRAFF have been developed in the recent past and they can be employed to produce optical, mechanical, and electronic components with micrometer or sub-micrometer form accuracy and surface roughness within nanometer range with hardly any surface defects.

DFFERENT AFM PROCESS

One Way AFM Process: One way AFM[1] process apparatus is provided with a hydraulically actuated reciprocating piston and an extrusion medium chamber adapted to receive and extrude medium unidirectional across the internal surface of a work piece having internal passages formed therein as shown in (figure 2).In this process abrasive media is pushed only in one direction and exit freely at the other end. The advantages of one way AFM process are faster cycle processing, easy clean up, larger parts can be processed and simplicity of the tooling.

Two Way AFM Process: The typical two way AFM process uses two vertically opposed cylinders to extrude an abrasive media back and forth though and around passages formed by the work piece and tooling. Abrasive action occurs wherever the media enters and passes through the most restrictive passages.The advantages of the two way AFM process are good process control, capability to finish ID and OD of the component, good control of radius generation, fully automated system capabilities, and faster change over of the media.

Orbital AFM

In orbital AFM, the work piece is oscillated in two or three dimension with a slow flowing bed of AFM medium. In orbital AFM surface and edge finishing are achieved by rapid,low-amplitude oscillations of the work piece relative to a self forming elastic abrasive polishing tool.Orbital AFM concept is to provide translational motion to the work piece.When the work piece with complex geometry translates,it compressively displaces and tangentially slides across the compressed elastic self formed bed which is positioned on the surface of the work piece.A small orbital oscillation of (0.5 to 5mm) circular eccentric planer oscillation is applied to the work piece so that,at any point in its oscillation,a portion of its surface bumps into the medium pad,elastically compresses and slides across the medium as the work piece moves along its orbital oscillation path.

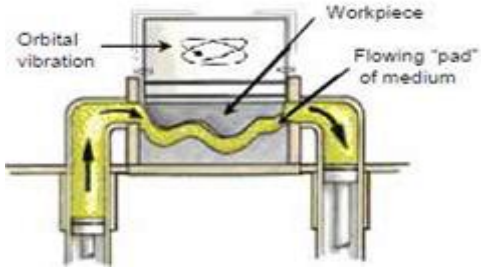


Figure 3

Magnetic Abrasive Finishing (MAF)

In this process, usually ferromagnetic particles are sintered with fine abrasive particles (Al_2O_3, SiC, CBN or diamond) and used as the bed. Figure 4 shows a Plane MAF process in which finishing action is generated by the application of magnetic field across the gap between work piece surface and rotating electromagnet pole. The enlarged view of finishing zone in Figure 4 shows the forces acting on the work surface to remove material in the form of chips. Force due to magnetic field is responsible for normal force causing abrasive penetration inside the work piece while rotation of the magnetic abrasive brush (i.e. North pole) results in material removal in the form of chips.

The magnetic abrasive grains are combined to each other magnetically between magnetic poles along a line of magnetic force, forming a flexible magnetic abrasive brush. MAF uses this magnetic abrasive brush for surface and edge finishing. The magnetic field retains the powder in the gap, and acts as a binder causing the powder to be pressed against the surface to be finished [2]. 3D minute and intricately curved shape can also be finished along its uneven surface. Controlling the exciting current of the magnetic coil precisely controls the machining force of the magnetic abrasives on the work piece [3].

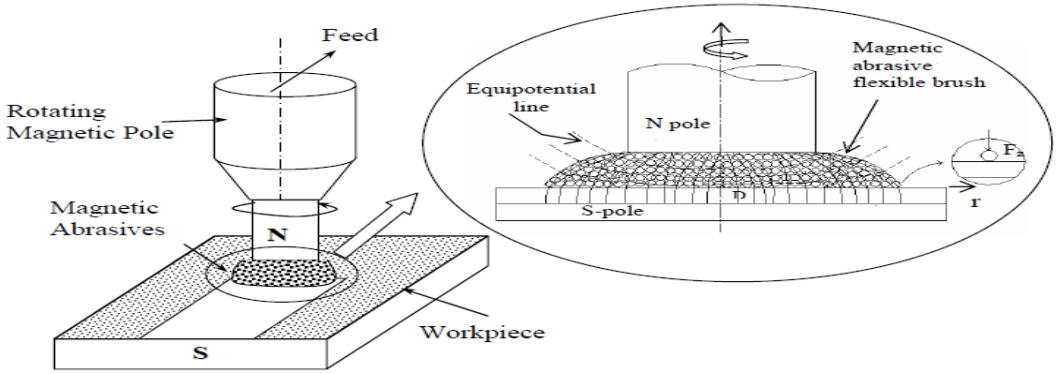


Figure 4: Plane Magnetic Abrasive Finishing

Magneto Rheological Finishing(MRF)

Lens manufacturing can be classified into two main processes: grinding and finishing. Grinding gets the lens close to the desired size, while finishing removes the cracks and tiny surface imperfections. The lens manufacturer generally uses its in-house opticians for the finishing process, which makes it an arduous, labor-intensive process. Perhaps the biggest disadvantage to manual grinding and finishing is that it is non-deterministic. To overcome these difficulties, Center for Optics Manufacturing (COM) in Rochester, N.Y. has developed a technology to automate the lens finishing process known as Magneto rheological Finishing (MRF) [4].

The MRF processrelies on a unique "smart fluid", known as Magneto rheological (MR) fluid. MR-Fluids are suspensions of micron sized magnetizable particles such as carbonyl iron, dispersed in a non-magnetic carrier medium like silicone oil, mineral oil or water. In the absence of a magnetic field, an ideal MR-fluid exhibits Newtonian behaviour. On the application of an external magnetic field to a MR-suspension, a phenomenon known as Magneto rheological effect, shown in Figure7, is observed. Figure 7a shows the random distribution of the particles in the absence of external magnetic field; In Figure 5, particles magnetize and form columns when external magnetic field is applied. The particles acquire dipole moments proportional to magnetic field strength and when the dipolar interaction between particles exceeds their thermal energy, the particles aggregate into chains of dipoles aligned in the field direction. Because energy is required to deform and rupture the chains, this micro-structural transition is responsible for the onset of a large "controllable" finite yield stress [5]. Figure 5c shows an increasing resistance to an applied shear strain,due to this yield stress. When the field is removed, the particles return to their random state and the fluid again exhibits its original Newtonian behaviour.

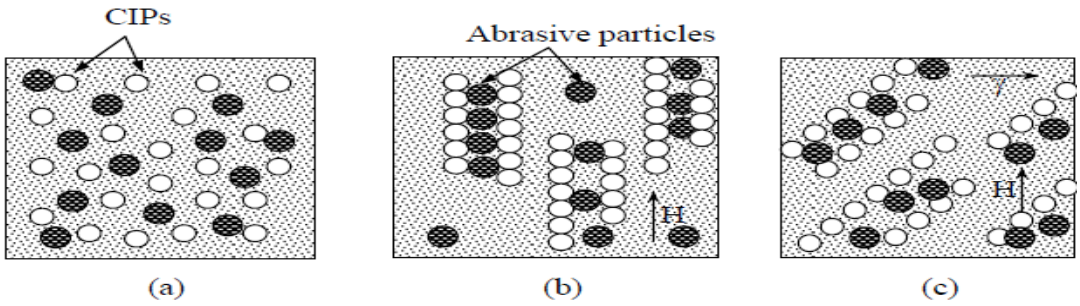


Figure 5: Magnetorheological Effect, (a) MRP-Fluid at no Magnetic Field, (b) At Magnetic Field Strength H and (c) At Magnetic Field H & Applied Shear Strain

Magnetic Float Polishing (MFP)

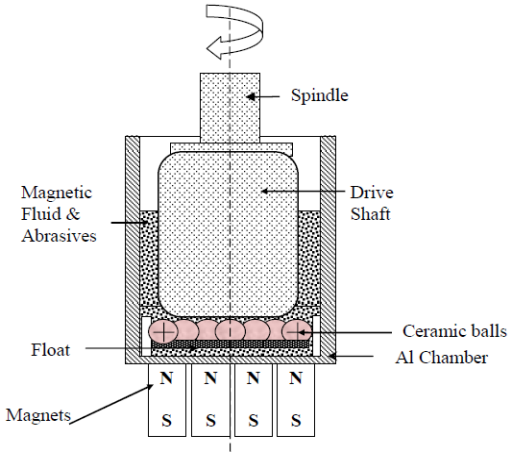


Figure 6: Magnetorheological Finishing Process

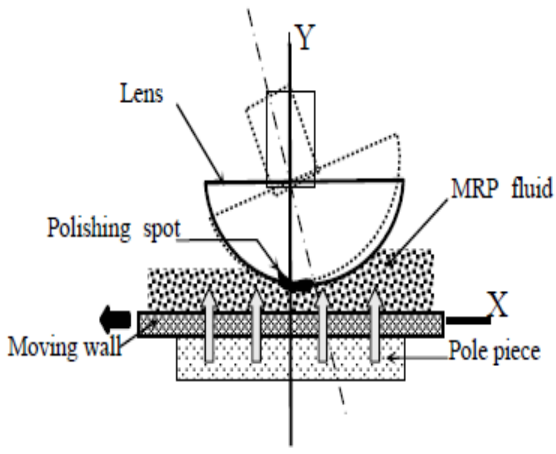


Figure 7: A Vertical MRF Machine [24]

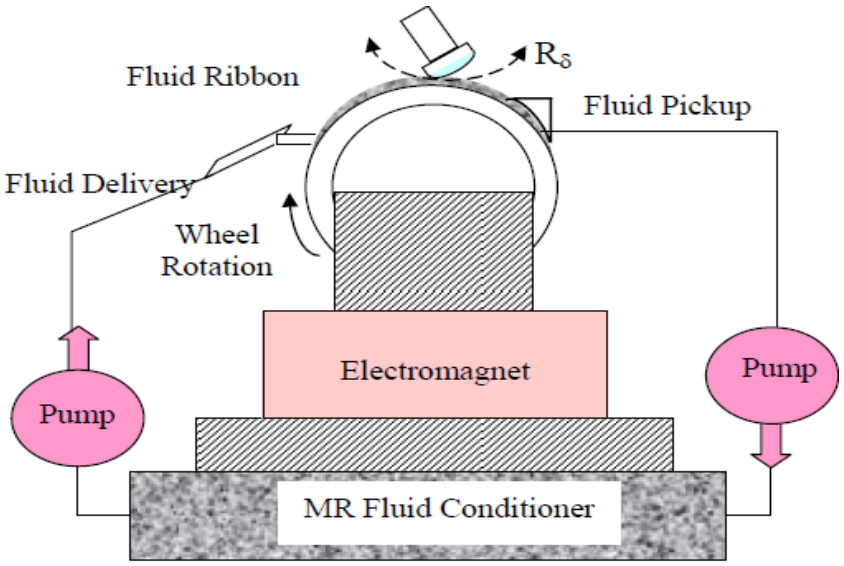


Figure 8: Schematic Diagram of the Magnetic Float Polishing Apparatus [30]

A recent advancement in fine abrasive finishing processes involves the use of magnetic field to support abrasive slurries in finishing ceramic balls and bearing rollers, and the process is known as Magnetic Float Polishing (MFP). The magnetic float polishing technique is based on the ferro-hydrodynamic behaviour of a magnetic fluid that can levitate a non-magnetic float and abrasives suspended in it by magnetic field. The levitation force applied by the abrasives is proportional to the field gradients and are extremely small and highly controllable. It can be a very cost-effective and viable method for super finishing of brittle materials with flat and spherical shapes. The schematic diagram of the magnetic float polishing apparatus used for finishing advanced ceramic balls is shown in Figure 8. A magnetic fluid containing fine abrasive grains and extremely fine ferromagnetic particles in a carrier fluid such as water or kerosene fills the aluminium chamber. A bank of strong electromagnets is arranged alternately north and south below the chamber. On the application of magnetic field the ferro fluid is attracted downward towards the area of higher magnetic field and an upward buoyant force is exerted on non-magnetic material to push them to the area of lower magnetic field [6].

The buoyant force acts on a non-magnetic body in magnetic fluid with magnetic field. The abrasive grains, the ceramic balls, and the acrylic float inside the chamber all being of non-magnetic materials, are levitated by the magnetic buoyant force. The drive shaft is fed down to contact the ball and presses them down to reach the desired force level. The balls are polished by the relative motion between the balls and the abrasives under the influence of levitation force and resistance [7].

Major Experimental Investigations on Abrasive Flow Machining

The primary advantage of abrasive flow machining is that it gives uniformity on polished surface compared to other manual methods which are tedious. This leads to improvement in performance and life of parts with reduction in overall cost.

Rhoades. L. J [8-9]studied the abrasive machining process and discussed important parameters like-extrusion pressure, flow volume, flow speed, medium viscosity, abrasives, work piece configuration and flow pattern which affects the performance of abrasive flow machining. The author has concluded that 85-90 % improvement can be achieved by approximately 0.0025 mm stock removal over the starting surface finish on original EDM surface. To improve original surface finish by 90% requires dimensional changes of approximately 50% more than the original surface finish. He has also explored the application of AFM for finishing, radiusing and removing recast layer on dies, fuel control valve, and

gears. In these application the surface finishing and radius reported by him are in the range of 0.03-0.2µm and 0.008mm respectively.

Jain V. K, Adsul S.G [10] carried out experiments to study the effect of process parameters on material removal and surface roughness for aluminum and brass work piece. They found in general that the dominant factors are abrasive concentration in media followed by mesh size, number of cycles and media flow speed. They claimed softer the material higher the material removal and more improvement in the surface fininish.

Gorana V. K et al [11] found that extrusion pressure, Abrasive concentration and grain size affect the axial cutting forces, radial cutting forces, force ratio (ratio of radial force to axial force) active grain density and their influence on reduction in surface roughness. On the basis of scanning electron microscopy they reported the possible mechanisms of material deformation are ploughing and rubbing.

Loveless T. R et al [12] performed experiments and found that amount of metal removed and improvement in surface finish by AFM process depends on previous machined process.The viscosity of the media also important. The role of extrusion pressure is limited. Researchers also found many similarities between AFM and surface grinding in context of material removal mechanism.

Rajeswar. G et al [13] reported mathematical model and computer simulation using Maxwell model for the media flow characteristic in AFM process and validates the model by experimental investigation. It is also concluded that a linear relationship exists between shear stress acting on the surface and thickness of material removed.

Jain R.K [14-19] presented the model for media flow for cylindrical work piece, solved by finite element method and used classical abrasion theory for simulation. The model predicts the radial stress and shows that material removal increases with piston pressure, abrasive percentage, but decreases with mesh size of abrasives. The roughness value decreases with increase in piston velocity, piston pressure, percentage of abrasives and mesh size for same number of cycles. They also simulated the generated surface roughness profile and material removal for abrasive flow machining with reference to percentage concentration, mesh size, extrusion pressure, number of cycles and reduction ratio.

A one dimensional modal for determine the specific energy by accounting process parameters of abrasive flow machining process also develop by them. They found that specific energy remains almost constant with change in abrasive mesh size and concentration. The microscopic technique has also developed to determine abrasive grain density.

Perry [20] presented principles and some industrial applications of AFM (precision deburring, edge contouring, surface refinement, removal of thermal recast layers.).It also pointed out abrasion is high where the media velocity is high. Media velocity is inversely proportional to flow area. If two holes have different diameters but total flow area, then they will get abraded equally. High viscosity media provides high material removal rate. Low viscosity is used for radiusing purpose. Likewise coarse abrasives are used for faster cutting and fine abrasives for flowing through small holes, or for highly polished finishes.

Przyklenk [21] described the effects of work piece geometry, surface roughness and change of microstructure near the machined surface with different media. It is concluded that with small bore dia more grains come in contact with the wall and material removal increases. With the increasing number of cycles first there is an increase in material removal due to higher initial coarseness of the work piece surface, then it slightly decrease per cycle. It is also found that the media should not be allowed to achieve temperature more than1000C to keep the viscosity of the media within the limits.

Studly[22] presented some applications of the process. For example, finishing of hundreds of holes in a disk in one operation, uniform and controlled stock removal of cast blades with minimum dimensional change, resizing of cooling holes in aircraft engine combustion liners, finishing of turbine components which otherwise are very difficult to machine.

Fletcher. A. J et al [23] investigate that the rheology of the (medium viscosity) grade polyborosiloxane contributes significantly to the success of the process. The rheotropic nature of the material indicates that the piston stroke capacity may be significant for determining the machining action. They also found that the thermal conductivity of the composite is sharply increases with concentration of the abrasives reached 50% by mass. The surface heat transfer coefficient at the interface between the media and die is primarily a function of abrasive concentration whereas the mesh size and polymer type have very influence.

Davis. P. J al [24] concluded that the temperature is an important variable in abrasive flow machining. For low viscous media to high viscous media there is a reduction in temp rise around 320C to 100C over 30cycles as well as both pressure drop and processing time increases. The relation between the number of cycles and both the temperature and pressure drop across the die are dependent upon medium type and abrasive-polyborosiloxane ratio. They found that average viscosity and pressure drop decreases as abrasives- polyborosiloxane ratio increases, irrespective of mesh size and type of PBS. The mesh size has minimal effect on rheological parameters.

Agarawal. A et al [25] fabricated viscometer based on the principle of visco-elasticity.By determining the creep compliance and bulk modulus,viscosity of the media has been found.Their experiments shows that viscosity of the media increases with the abrasive percentage and decreases with the temperature. They also concluded that the media has a well defined viscosity and mechanical behavior close to Kelvin solid.

Williams and Rajurkar [26] applied acoustic emission technique for online monitoring of material removal and surface roughness in AFM process. They found that abrasive concentration and abrasive size are the key factors in deciding material removal and surface finish. Effect of extrusion pressure not much significant. The interaction effect between abrasive size and abrasive concentration is the only significant interaction effect.

APPLICATIONS

Advanced high-pressure injection system components in diesel engines are subjected to repeated pulses of very high pressure that can generate fatigue failures at high stressed areas. Smoothing and removing surface stress risers, cracks, as well as uniform radiusing of sharp edges by AFM process can significantly extend component life. Flow tuned spray orifices of fuel injector nozzles can reduce particulate emissions and improves the fuel efficiency of diesel powered engines.

Applications that use high precision lenses include medical equipment such as endoscopes, collision-avoidance devices for the transportation industry, scientific testing devices and military's night vision equipment like infrared binoculars. Missiles are equipped with a wide variety of high precision lenses for navigation, target location, and other functions. The nano diamond doped MR fluid removes edge chips, cracks, and scratches in sapphire bend bars.

It is widely used in automobile industry as it increases surface quality and uniformity of finished components. The machine components which is machined by AFM, increases flow velocity and engine performance.It Improves fuel economy and fuel efficiency.

Since in the AFM process abrading medium conforms to the passage geometry, complex shapes can be finished with ease. Dies are ideal work pieces for the AFM process as they provide the restriction for the medium flow, typically

eliminating fixturing requirements. The uniformity of stock removal by AFM permits accurate sizing of undersized precision die passages.

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